

Amateur Cleanrooms: Costs May Not Offset Benefits
W. Lawrence Ramsey, P.E.
NASA, Goddard Spaceflight Center, Greenbelt Md.
Contamination and Coatings Branch

During my career at NASA, I have encountered a variety of cleanroom systems. With many projects, cost pressures and lack of adequate facilities have forced the managers to resort to amateur cleanrooms to manufacture spacecraft and instruments. These rooms are usually spaces that have been used for other purposes that are converted to cleanrooms, usually without the assistance of a contamination control specialist. Often, scientists and engineers are successful in converting an area for experimental use. However, when the area is used for production, countless difficulties are encountered. This paper will document some of the disasters that I have personally witnessed and offer some guidelines for contamination professionals to follow if you are called upon to assist in the development of new cleanrooms.

Cleanrooms come in all shapes and sizes from special purpose mini-environments (such as flow benches) to large, expansive production facilities. These areas may require a variety of unit operations to be carried out within a short range of each other. The design of the cleanroom should account for compatibilities of these operations to protect the product and personnel. The level of cleanliness has traditionally been associated with the method of ventilation. However, just because an area has HEPA filters and greater than 20 air changes per hour does not mean that it is a cleanroom. Airflow is extremely complex; the only way to properly design a cleanroom is through the use of a computer based model.

In the aerospace industry, few engineered cleanrooms are modeled. Modeling has been perceived as expensive; however, modern programs and fast computers are changing perception. It is the lack of appreciation for how air flow and location within a cleanroom affects the product that causes most of the problems I have experienced. Currently, the rules defining the best air flow design practices are based on simplistic historical data that are often wrong. The performance of a cleanroom is defined by a set of complex interactions between the airflow, sources of contamination and heat, position of the air terminals and exhausts as well as the objects occupying the space in question. These subtleties are almost never appreciated in the setup of amateur cleanrooms (and sadly, in some engineered cleanrooms as well). Experience with the room, measurement of air flows in the room, and black light inspections can be used to guide a contamination specialist in modifying a setup to improve conditions in the absence of models.

There are situations where conditions in amateur cleanrooms make it impossible to rescue the area. These problems include:

- Not recognizing that humans are a principal source of contamination and that may limit the number of workers permitted in an area.
- HEPA filters are installed but airflow not enough to keep positive pressure allowing unfiltered air to enter the room.
- Materials may have been used in the construction of the cleanroom that produce particles or outgas unacceptably.
- Materials of construction may contain contact contaminants i.e., phthalates or silicones that can cause molecular contamination.
- Improper fit of materials allows movement caused by building vibrations to generate particles.
- Rooms that were converted can have particles crammed into every joint that act as an invisible source of contamination.
- Some areas use building air that may contain organics (like shop oils and popcorn grease) rather than have a controlled source of air.

Other assumptions on the savings over engineered cleanrooms can be misleading because the project using an amateur cleanroom may not understand what is included in the costs for engineered cleanrooms. These cost assumptions include:

- Cost to monitor and certify an amateur cleanroom is the same as an engineered one.
- Cost to maintain an amateur cleanroom is the same as an engineered one. (Monitoring, cleaning, garment replacement, chemicals, etc.)
- Sometimes maintenance costs for these amateur cleanrooms are actually higher than engineered cleanrooms. If the location requires extra transport time for cleanroom crews to be brought from a central location the maintenance costs may be higher.
- Specialized cleaning equipment must be purchased and stored at the site.

Not only does it cost to maintain the room properly, if the area is suffering from limiting suitability problems, other major costs may occur such as:

- Delays caused by remanufacturing components that failed to meet specifications can cost more than potential savings.
- Parts get damaged during additional cleaning cycles and must be replaced.
- Sometimes you do not find problems until the product is shipped or the spacecraft is launched.

Several projects that I have worked have suffered through the amateur cleanroom problem. They are included here by example-not of poor decisions but of what could happen. I have also worked on projects that did not have problems as challenging as these in spite of the poor facilities. I suggest that it is better to rely on skill than trust to luck.

The Yellow Room

The Yellow Room is a QA lab and store room in a high bay machine shop that was converted to a cleanroom. The conversion was done about thirty years after the area was constructed. Figure 1 shows a view of the room looking toward the rollup door to the exterior and the overhead crane. From this view you can make out the entrance to the room, its poorly fitting rollup door (lower right corner), and tool cage where the ventilation and HEPA filter bank is located.

Figure 1

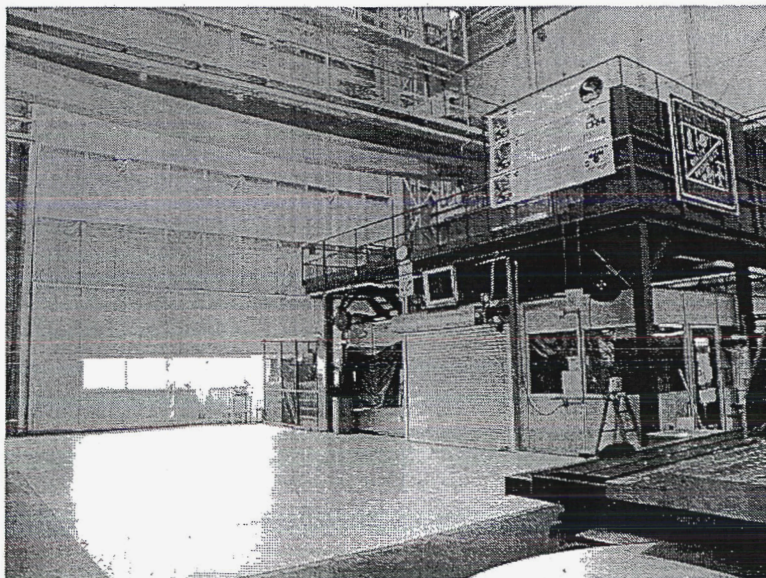
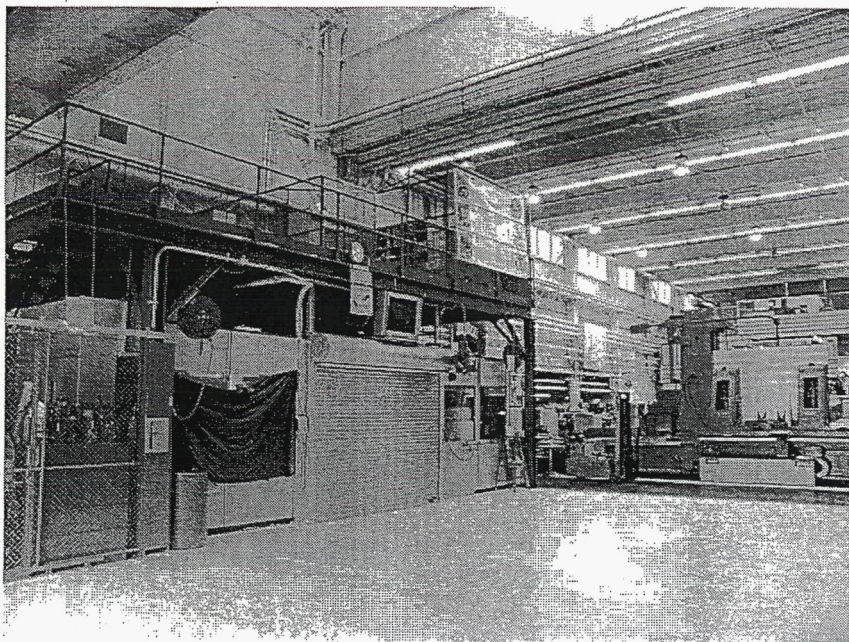


Figure 2 is a photograph of the room from the roll door looking toward the machine shop. The photo shows the current air return plenum on the exterior of the Yellow Room. The black plastic is used to keep the room dark for the frequent inspections/cleanings needed to control particles.

Figure 2

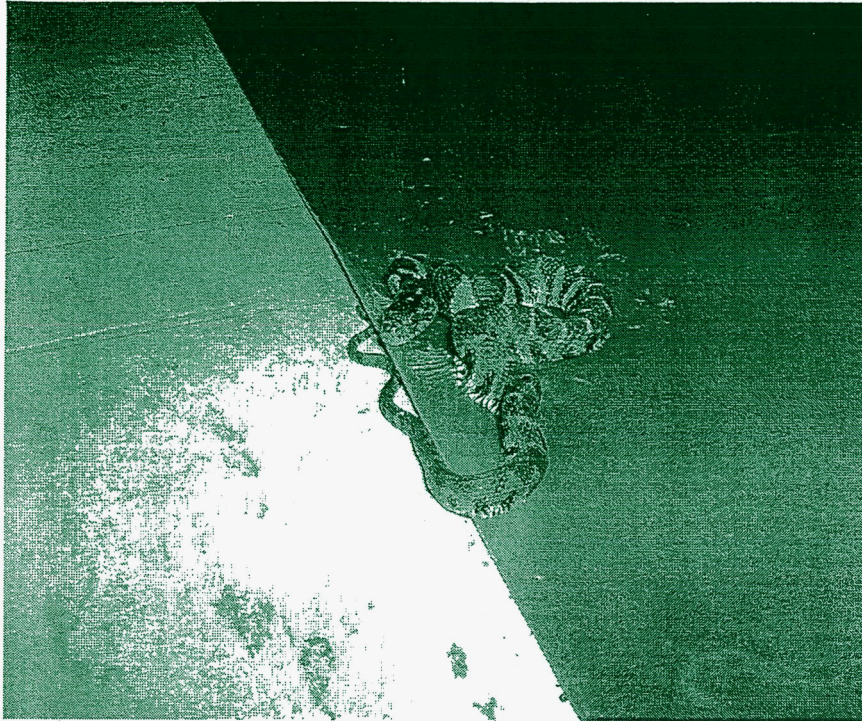


NASA was assembling two identical coronagraphs in this room. Soon after start of assembly, we encountered a fly infestation apparently due to the frequent openings of the high bay door. Several months later we encountered a mouse problem. A mouse had entered the room by chewing a hole in the tape over the hole in the corner of the Yellow Room roll up door. We found droppings and hair all over our work surfaces. Our problem was solved by a snake that ate the mouse and conveniently caught itself on the tacky mat in the entrance to the work area (Figure 3).

Before the project started build up of the instrument, the cleanroom technicians reported that much of the cleanroom materials of construction were not cleanroom compatible. The room electrical conduits were aluminum and we had to tape over them. Several of the ceiling tiles were loose and were also taped. I had also noticed the whenever the door to the room was opened and closed, some of the ceiling tiles moved. We ended up taping all the tiles in place. A sheet of bagging film was used to cover up the Yellow Room roll up door.

After the flies and snake/mouse episode, I was sure that we had run out of our bad luck. Then the fire occurred. One of the fan motors burned up over a weekend. Fortunately, our protocol was to store all optical parts in sealed containers when we were not working on them. Had the fire occurred during the week, we would have to re-clean and bakeout components. Inspection of the motor revealed that it was coated with material from the machine shop. Part of the problem was that the motor did not have a thermal protection circuit. The plenum had three such fans. We rewired the system with modern fans on separate circuits.

Figure 3



Then came the flood. It seems that the filter box the held the HEPA filters was made of particle board. On one very humid day the shop roll up door was opened for a long time. The little drain under the air conditioning coils was overwhelmed and the drip pan over flowed into the Yellow Room. Being made from particle board, the filter housing deteriorated almost overnight. The solution was to construct a new plenum from stainless steel. In spite of the changes and improvements to the Yellow Room, the second coronagraph was not acceptable due to particle contamination. The project was trying to save about \$20,000. My estimate of the cost incurred due to delays, construction, re-certifications, and repair was about \$500,000.

The Room 150 Clean Tent

This spacecraft was not particularly sensitive to contamination. The project had proceeded for some time without a contamination engineer on board. At the insistence of the science team, I was called in to make an assessment of the situation. This occurred just before a vacuum test at cryogenic temperatures was begun to test the optical alignment stability at operating temperatures (70°K). My suggestion was to build the spacecraft in clean tent and delay the vacuum test until a method to prevent moisture from condensing on optics was developed. The recommendations were ignored as being too costly. After vacuum test, one of the optical elements exterior coating peeled off apparently due to moisture condensed inside the coating and then freezing. The project reconsidered my recommendations. At Goddard, we have a contractor administer our cleanrooms – Mantech. I began discussing modifying an existing clean tent for this project's use because on its fixture, the spacecraft was too tall for the current tents. The plan was to acquire higher jack stands and a longer tent for an existing down flow HEPA array. Then I made a mistake, I took a few days off. When I returned, the project had decided to not wait for the fix and chose to buy another tent. Figures 4 and 5 show the details of the tent the project had purchased.

Figure 4

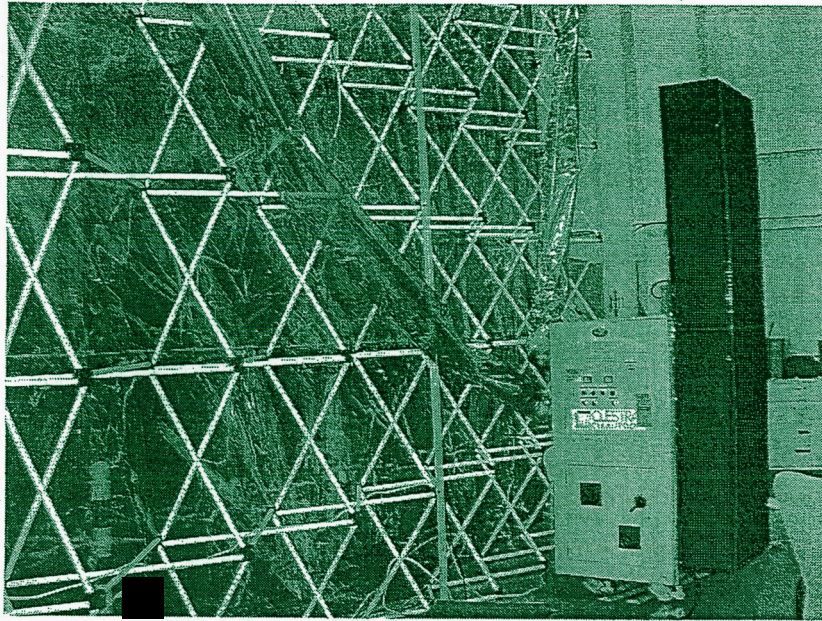
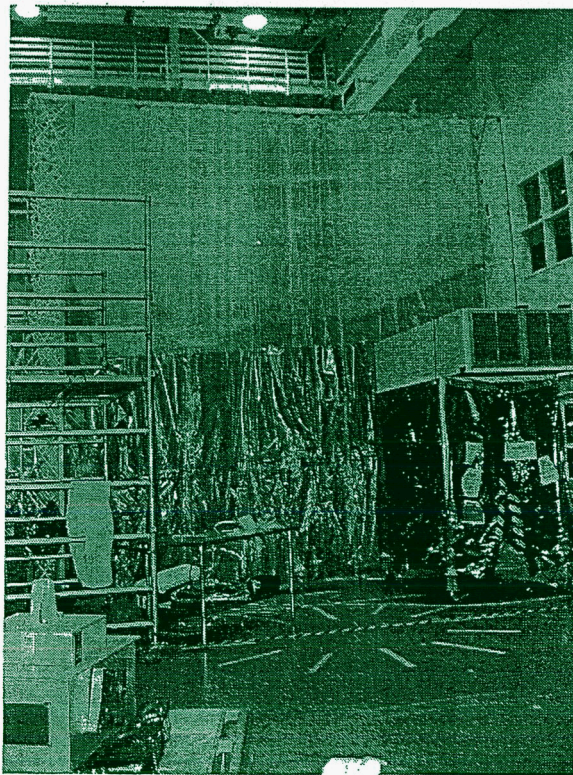


Figure 5



As you can see, it's not a clean tent. In spite of my protests, the project continued to develop this option. Figure 4 shows the portable air-conditioning unit (PAC) that was used to supply HEPA filtered air to the tent. The tent arrived with a material that carried a static charge. A major problem for an ESD sensitive

spacecraft. We had to hang metallized bagging film inside the tent to prevent damage to the spacecraft. The PAC could not supply enough air to make the tent comfortable for workers (or class 10000 for the spacecraft). Another PAC was brought in to circulate cold air and control humidity. The primary instrument on the spacecraft is ESD sensitive so it likes moist air but it's detectors are sensitive to moisture, so they like dry air. I suggested contamination covers for the instrument that would be purged. This enabled them to proceed. But the project was still plagued with humidity problems on the ESD side.

The material used for the inlet ducts was not cleanroom compatible. Its lining broke down and showered the space craft with particles. We had to shut down, replace the ducts, clean everything, and re-establish humidity conditions.

Where were the savings? With all the adjustments to the tent, it took just as long to get up and running with the tent as the expected delay to modify an existing clean tent. The rent on the two PAC units and the amortized cost of the tent were about the same as the rental on the clean tent. The cost to add the film for ESD, extra cleanings, and maintenance on the inlet ducts were extra. The clean tent that I had tried to modify would have had a larger foot print than the tent. The space craft was damaged several times by the scaffold in the tight quarters.

I think that the real problem is the difficulty for project managers and engineers working outside their field to appreciate what contamination control is supposed to do. Explaining why these people attempt to design a system that they do not understand, is a mystery. Equally mysterious, is why a project would hire a contamination control specialists only to ignore their advice. Hopefully, the paper can be used to discourage people from trying to ignore or obtain the advice of contamination professionals.